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WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

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UNIFORMLY-SENSITIVE LINE HYDROPHONES (U)

by

S. T. Knott, F. R. Hess and R. T. Nowak

January 1969

TECHNICAL REPORT

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ABSTRACT

(U) A uniformly-sensitive line hydrophone under development at the Woods Hole Oceanographic Institution has been used to receive broadband seismic reflection signals.

(U) The directivity characteristics of an adequately-long continuous line sensor used in a broadband sound field (less than 10 Hz to several kHz) are not easily obtained by arrays of discrete sensors. Discrete element arrays in a sound field of such wide frequency range inevitably develop side lobes of full sensitivity at a number of frequencies at various angles to the array. It is of particular utility that the side lobes of a continuous line hydrophone are each successively reduced.

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INTRODUCTION

(C) During the past year long lengths (30 to 300 meters) of continuous-element line hydrophone have been applied to the directional reception of broadband sound. These hydrophones, under development at the Woods Hole Oceanographic Institution, are capacitive transducers of uniform coaxial configuration. Their development has resulted in an improved directional reception of broadband seismic signals (from less than 10 Hz to several kHz) with emphasis on the reception of the lower frequencies and on the rejection of noise.

(U) One of the more powerful techniques for determining the sediment and rock structures below the oceans is that of continuous seismic reflection profiling.^{1, 2} Continuous seismic reflection profiles resemble echo-sounding profiles, but the broadband sound pulses used are rich in low frequencies and penetrate as well as reflect from the seafloor and from acoustic discontinuities below. The spectra of these reflections can change geographically due to a change in the reflector's depth below the bottom, as well as to a change in the geological structure of the reflectors. Broadband sound is employed intentionally so that the frequency dependence of reflections from the seafloor and the formations below can be examined. It is therefore important that the receiving hydrophones also have a broad response.

(U) Since profiling is an underway operation, the towed receivers cannot be far removed from the ship which is usually a sizeable noise source. This noise background is most predominant in the infra-sonic (sub-audio) to lower sonic range and noise spikes are common. Additional noise, through which the broadband signals must be received is created by towing the receiving transducer through the water. Since the average spectra of the noise and the seismic reflections are often similar, a receiving transducer has been sought that would discriminate against both ship generated noise and towing noise, receiving preferentially the broadband reflected signals from the seafloor.

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(U) A truly continuous line sensor meets most of these requirements, for such a transducer has only one maximum lobe at any frequency as well as adequate directivity for all frequencies having wave lengths equal to or less than the length of the line. Such a response is not easily obtained with arrays made of discrete receiving elements. Both a multi-element and a continuous line array in general receive at peak response those sounds whose path is normal to the line. When an array of discrete elements is used in broadband applications, however, side lobes also develop peak response at angles other than 90° depending on the wavelength of the sound, the element spacing, and the direction of propagation with respect to the axis of the array. In comparison, the side lobes developed by a continuous line hydrophone always have less than peak response. If any sound (including noise spikes and self-generated tow noise) is not received simultaneously along the full length of the continuous line, the response of the line is significantly attenuated by the shunt effect of that part of the line which is not similarly insonified. This effect is not realized with more conventional arrays, in part because of the space between elements.

(U) Examples of the difference in response between a linear five-element array and a continuous line hydrophone are shown in Figure 1. In these diagrams the response as a function of the angle between the sound ray path and the axis of the array is shown for frequencies which have wavelengths equal to the array length, equal to one-half the array length, equal to one-fourth, and one-eighth the array length.

(U) A search of the relevant literature has not revealed any extensive use of capacitive line hydrophones in underwater acoustical applications. Stein and Wallace³ and Repici⁴, have made some use of a ribbon-like capacitive line hydrophone in their sonobuoy work, and Hunt and others at Harvard⁵, have considered the application of the microphonic and capacitive characteristics of coaxial cables.

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RESULTS

(U) Several thousand miles of seismic profiles have been made to date using the continuous line hydrophone. Figure 2 shows examples of deep-water profiling records obtained with a 30-meter length of the line hydrophone and with a five-element array while using an under-water spark sound source with 80 kilojoules of stored energy. The line hydrophone or WHOLINE as it is called, was towed 90 meters behind the ship's propellers. At the same time the five-element array of Chesapeake P100 transducers was towed 130 meters astern, a distance at which the background towing noise received by the array was greater than or equal to the ship-generated noise. The speed of the ship was about 5.5 knots. The receiving bandwidths of the two examples were essentially the same and gains were adjusted to make signal levels roughly equal. Similar results were obtained under less advantageous conditions when the WHOLINE was towed only 25 meters astern.

(C) The coaxial line consists of strength members and auxiliary conductors in the center surrounded by a buoyancy control material such as dense foam or solid polyethylene (Figure 3)⁶. A coaxial capacitor with flexible foils and a compressible dielectric is built over this central core. A waterproof, abrasion-resistant, outer sheath covers the entire line. The outside diameter is roughly one inch. These hydrophones are quite rugged, particularly a later model having steel strength members. The hydrophone can be run over sheaves and otherwise handled like a light-weight cable of similar size.

(C) The capacitance of the hydrophone is about 1500 pico-farads per meter at 20°C. The change in capacitance due to acoustical pressures has been detected by charging the line capacitance to some potential and then amplifying the change in potential due to variations in capacitance.

(C) Rates of change of capacitance with temperature and pressure for 0.3 meter-long samples of the hydrophone have been measured in a pressure vessel. Samples of the type of hydrophone used to obtain the records shown in Figure 2 have a fractional change in capacitance of about 10^{-8} per μ bar which would predict a sensitivity of about -120 db re 1 volt per μ bar for a charge voltage of 100 volts. A second less sensitive model used successfully in shallow water work has a fractional

change in capacitance of about 0.4×10^{-8} predicting a sensitivity of about -130 db re 1 volt per μ bar at a polarizing voltage of 100 volts. The average fractional change in capacitance over the range of pressure from 0 to 3×10^6 μ bar gauge as a function of temperature for 0.3 meter samples of these two cables is shown in Figure 4.

(C) These sensitivity values are in general agreement with preliminary measurements made by comparing bottom echo signal levels simultaneously received by the line and other hydrophones. The field measurements yielded a somewhat higher sensitivity, about -85 to -105 db re 1 volt per μ bar at 20°C with a charge voltage of 100 volts.

(C) The materials of the compressible dielectric, sheath, and outer-foil stiffen at low temperatures. Because both the capacitance of a unit length and the incremental change in capacitance with pressure decrease with temperature, there is a loss in sensitivity at low temperatures. Characteristics of other materials are being investigated.

(C) Preliminary measurements of the frequency response of the hydrophone indicate it has a useful frequency response from static pressure to about 10 kHz. For example, 12 kHz echo soundings have been received in addition to the low frequency seismic reflections. In actual use, however, any deviations of the hydrophone from a straight line has the effect of causing the hydrophone to act as a low-pass filter and such deviations are somewhat difficult to prevent when towing a long line.

(C) A number of measurements of tow noise have been made on the 30-meter lengths. Although the analysis is incomplete, the tow noise appears to be related to a combination of the length and frequency response of the line, and the frequency of vibrations along the tow cable and the line. A reduction in tow noise has been noted as speed is increased from five to about eight knots which may result from an upward shift in the frequency of vibration.

CONCLUSIONS

(C) Although this work is still in an early stage of development, it is clear that the unique directional characteristics of a truly continuous line hydrophone are of value in the reception of broadband sound signals as has been demonstrated in seismic reflection profiling. Although a single line cannot be steered, groups of lines can. A piece of line, arranged as a segment of or as a complete circle, or as a cross of several lines can provide an additional dimension of directionality.

(C) There are at this time problems of pressure and temperature effects related to the choice of materials, as well as variations in sensitivity from one piece of the manufactured material to another. In spite of these problems, the cost of experimental lengths is currently less by an order of magnitude than the cost of conventional linear multi-element arrays. At these costs the selection of suitable pieces from large runs of material is a practical venture.

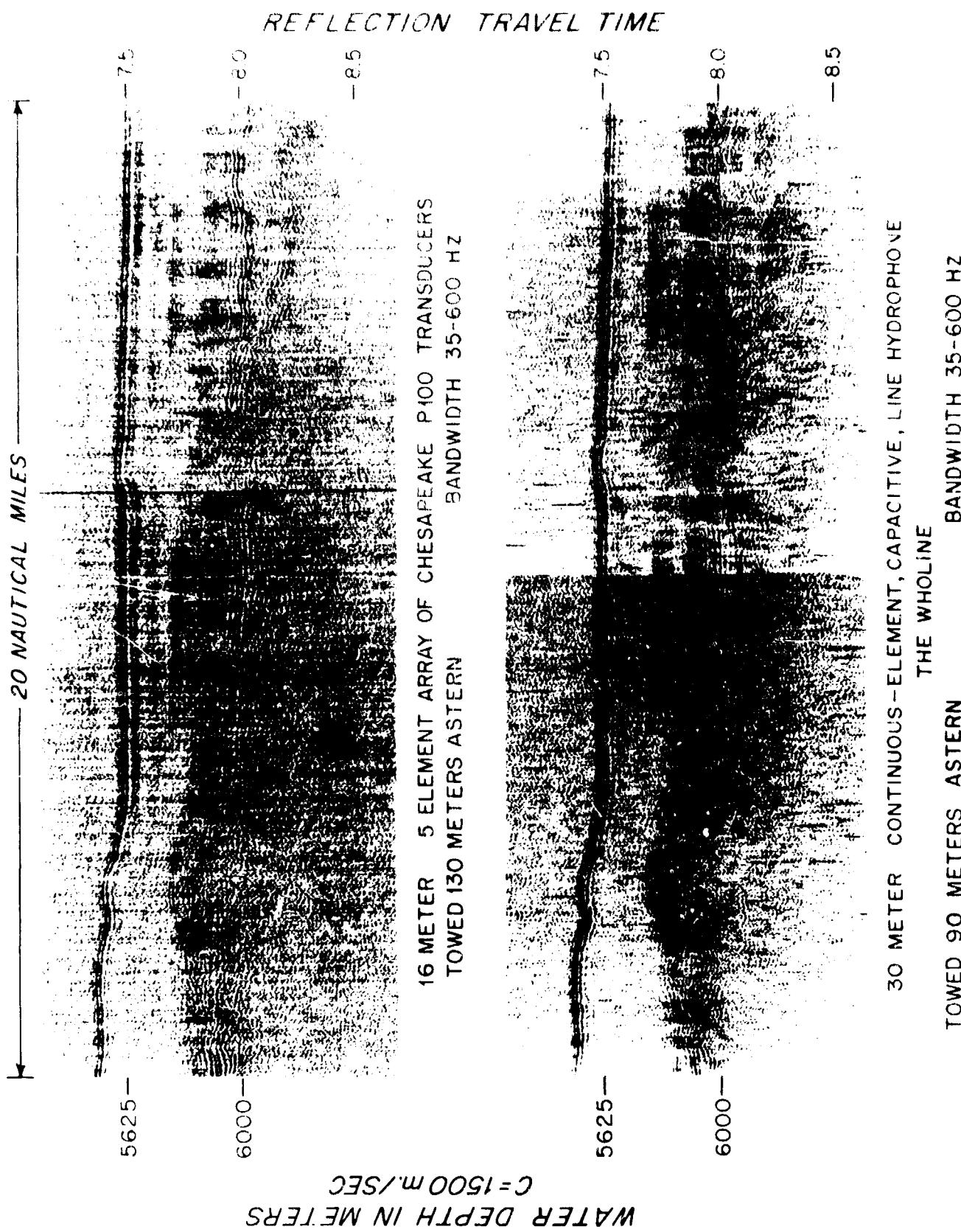
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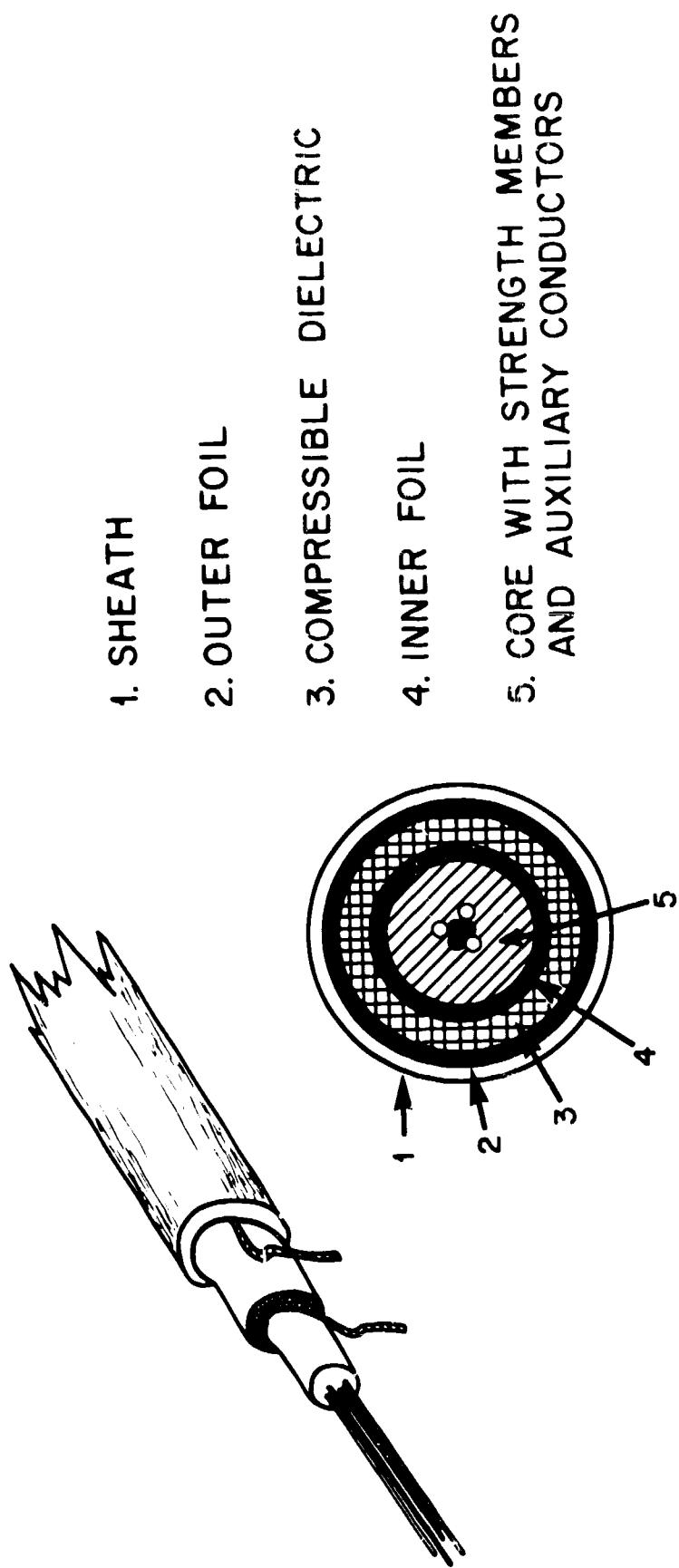
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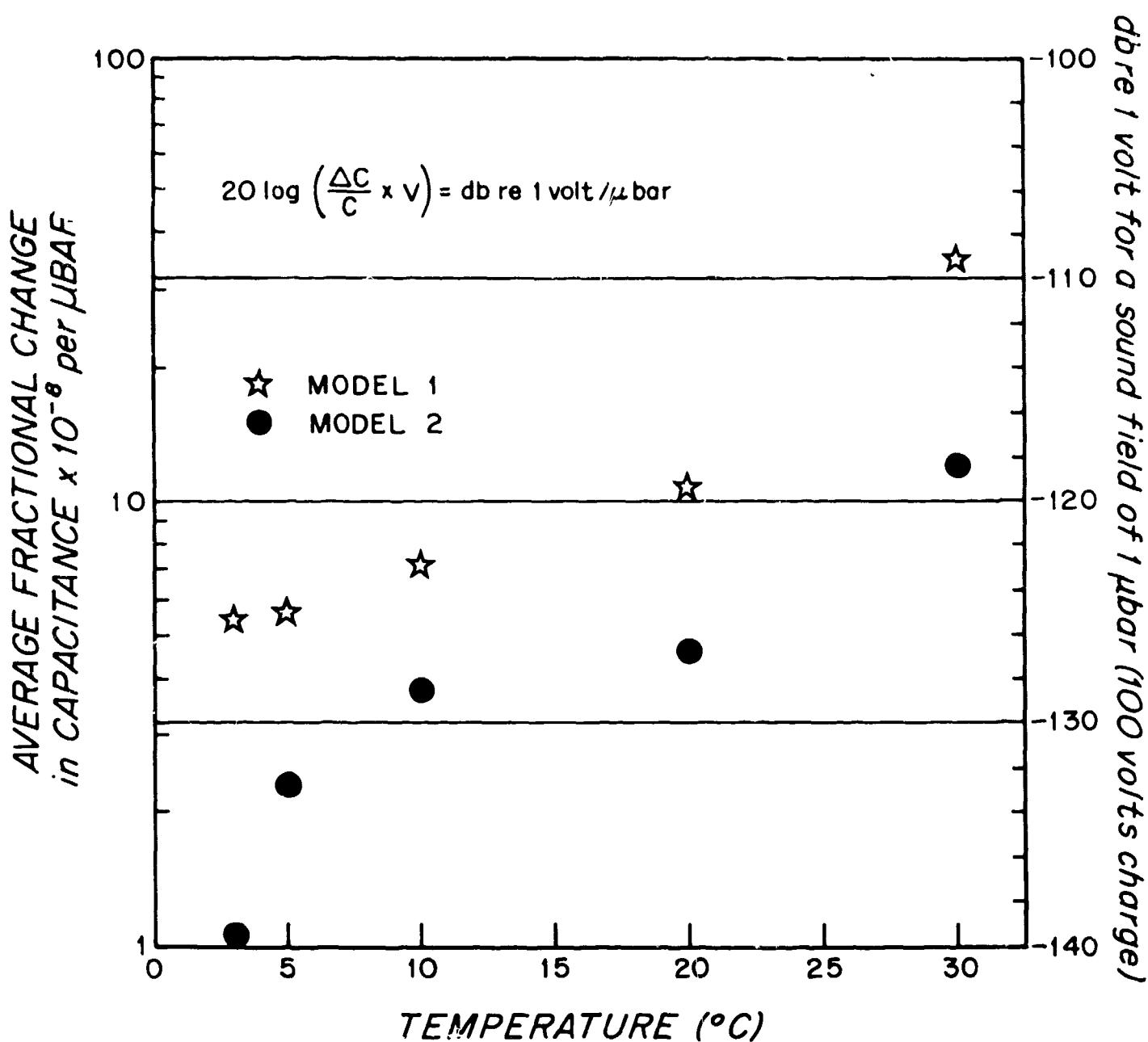


(C) Figure 2. A comparison of continuous seismic reflection profiling results. (U)

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(C) Figure 3. Construction of the continuous line hydrophone. (U)



(C) Figure 4. Average fractional change in capacitance and sensitivity in the range of 0 to $3 \times 10^6 \mu\text{bar}$ static pressure as a function of temperature. (C)

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F. P. Hess and R. T. Knak, 13 pages. January 1969. Contract
Nonr-402(100), No 260-101.

(1) A uniformly-sensitive line hydrophone under development at the Woods Hole Oceanographic Institution has been used to receive broadband seismic reflection signals.

(2) The directivity characteristics of an adequately-long continuous line sensor used in a broadband sound field (less than 10 Hz to several kHz) are not easily obtained by arrays of discrete sensors. Discrete element arrays in a sound field of such wide frequency range inevitably develop side lobes of full sensitivity at a number of frequencies at various angles to the array. It is of particular utility that the side lobes of a continuous line hydrophone are each successively reduced.

1. Towed hydrophone arrays
2. Directional response of simple arrays
3. Continuous line hydrophone
4. Signal-to-noise ratio of towed hydrophone array

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II. Hess, F. P.
III. Knak, R. T.
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